Seabed reflection uncertainty coupled to geoacoustic uncertainty

ONR Uncertainty DRI
Annual Review
Providence, RI
June 19, 2003

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Research Objectives

LONG RANGE GOAL:

Develop methods for characterizing uncertainty and variability in seabed geoacoustic data

- meso-scale: lateral scales $O(10^{2})$m; vertical scales $O(10^{-1}-10^{1})$m via seabed reflection data (100-10000 Hz)
- fine-scale: lateral scales $O(10^{-1}-10^{0})$m; vertical scales $O(10^{-2}-10^{-1})$m via seabed scattering data (600-3600 Hz)

SHORT-RANGE OBJECTIVE:

Determine uncertainties in acoustic measurements (reflection) and how those uncertainties transfer to geoacoustic property uncertainty

OUTLINE

I. Measurement Uncertainty of Seabed Reflection

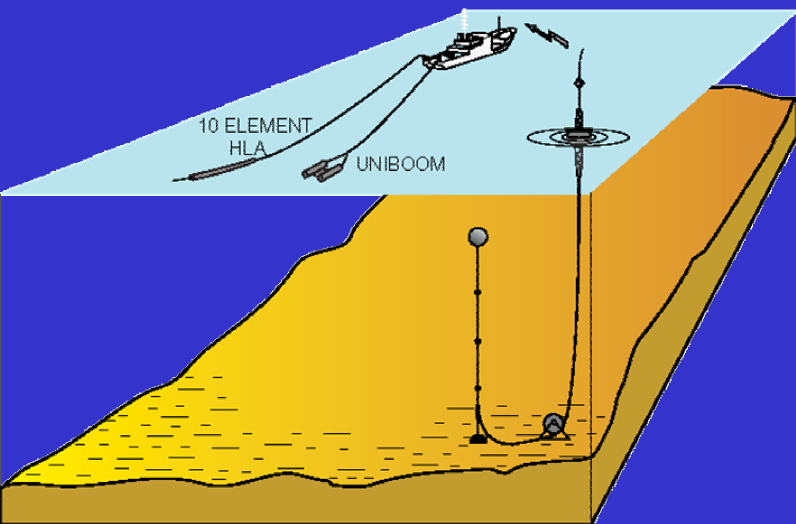
- A. Measurement Technique
- B. Uncertainty Analysis (predictive, observational)

II. Geoacoustic Uncertainty (with Stan Dosso, U Vic)

- A. Error estimation (data and model)
- B. Optimal Fits/statistics
- C. Marginal Prob distributions and parameter correlations

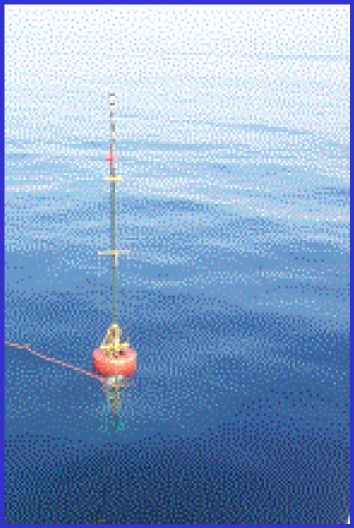
III. Signal-to-Reverb Uncertainty (with Chris Harrison, SACLANTCEN)

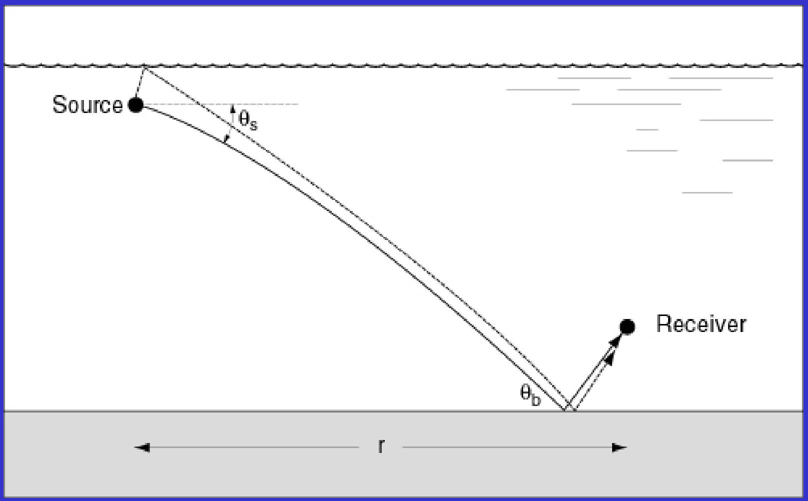
Bottom Reflection Receiver



Receiver

Telemetry



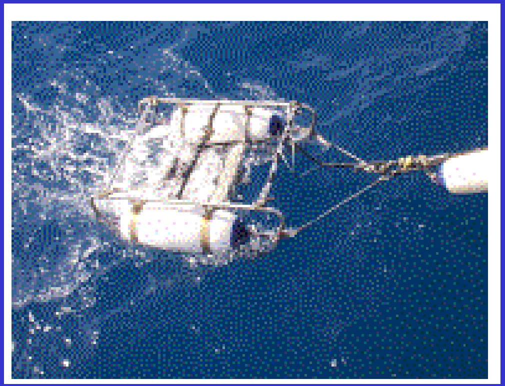


Characteristics

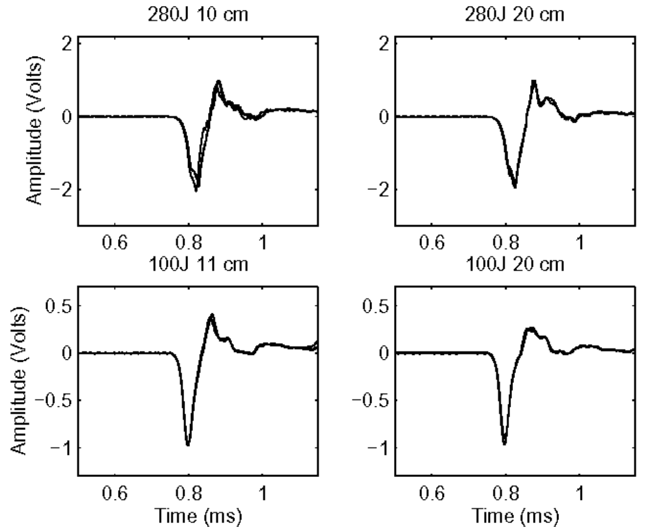
- 20 bit dynamic range
- 10 Hz - 20 kHz bandwidth
- low power requirements
- Lightweight sonobuoy-type package

Bottom Reflection Source

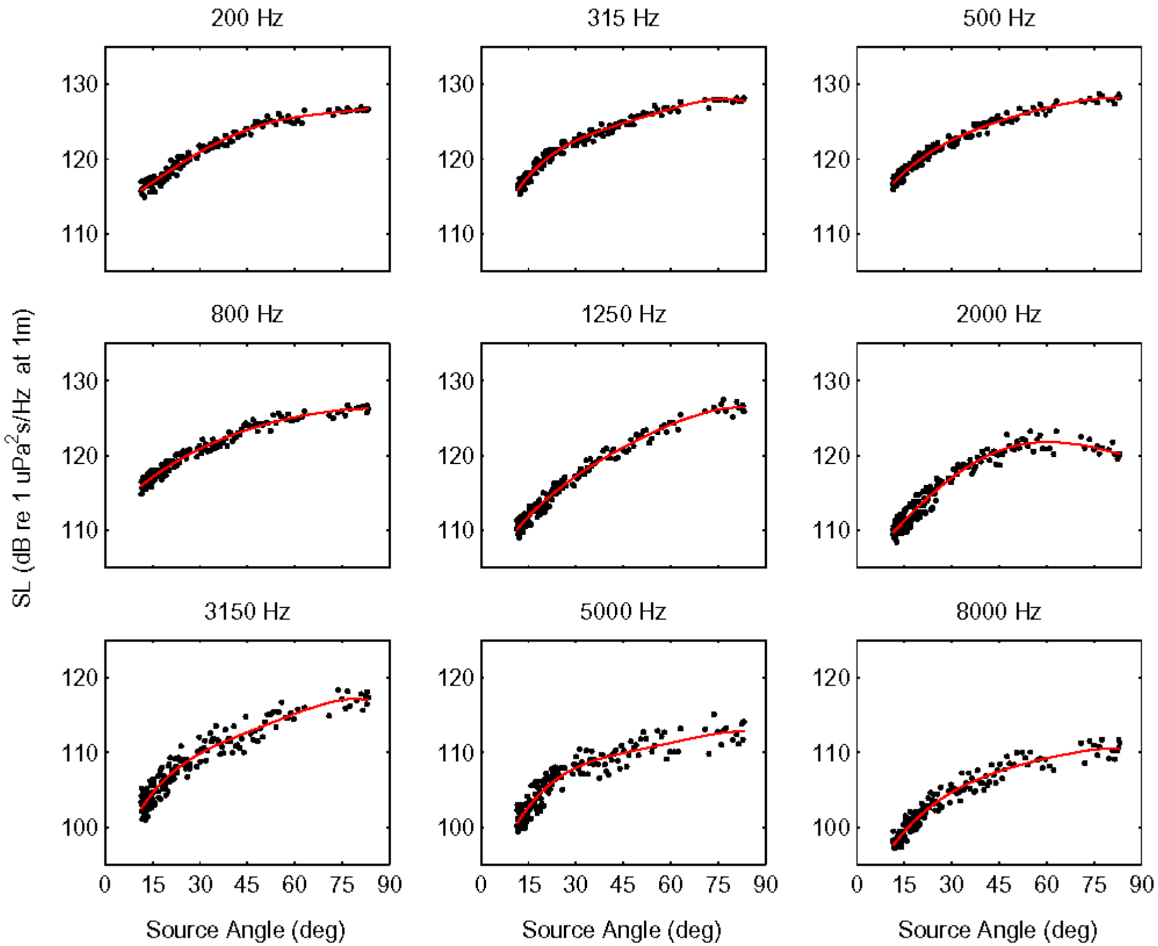
Uniboomer Source



Source level: tank data 3 pings



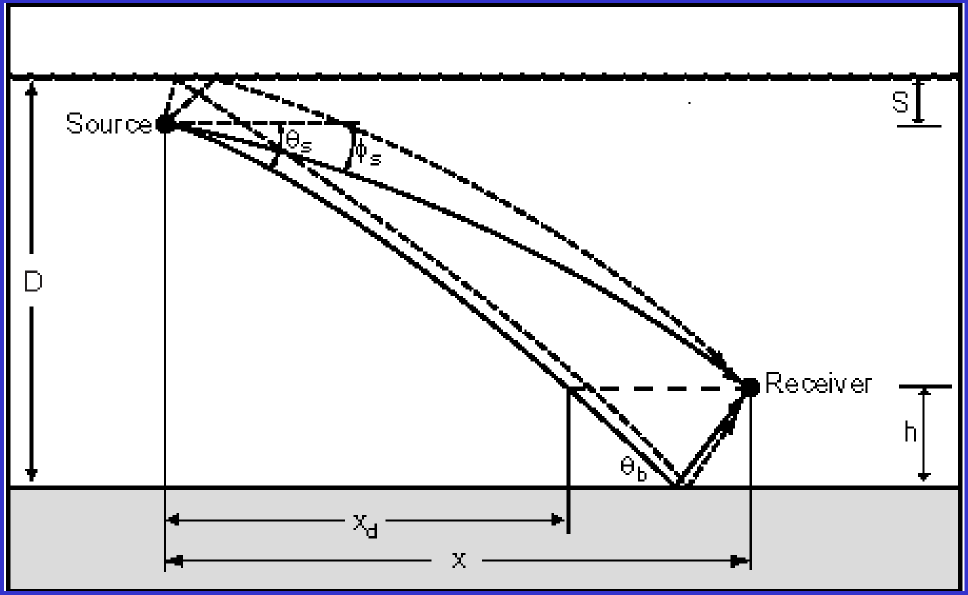
Source level: Field data



Data Processing Eq.

$$\left|R(\theta_b, f)\right| = \left|\frac{p_r(x, f)}{p_o(x, f)}\right|$$

$$\left|R(\theta_b, f)\right| = \frac{\left|p_r(x, f)\right|}{q_d(x_d, f)} \frac{\gamma_d}{\gamma_o}$$



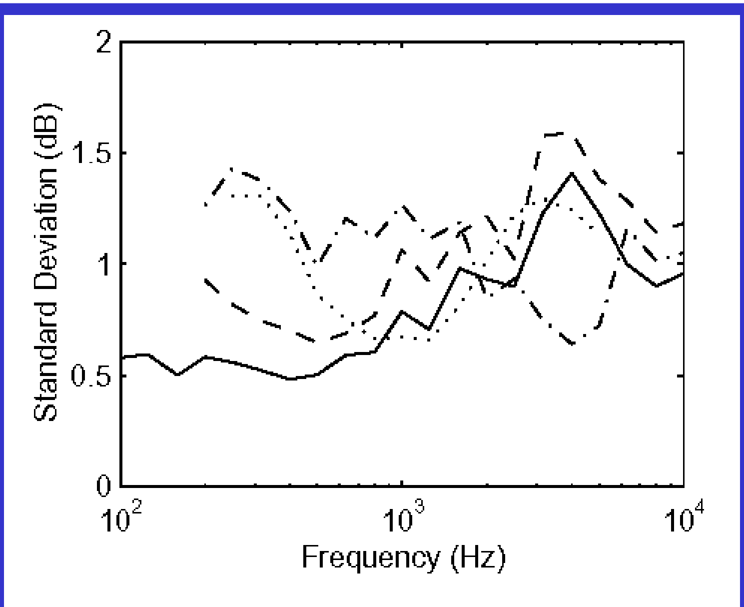
$p_{r/d}$ pressure of bottom reflected/direct path

q_d fit of source level data

$\gamma_{o/d}$ transmission factor for bottom reflected/direct path

Uncertainty Analysis: SL

$$\left|R(\theta_b, f)\right| = \frac{\left|p_r(x,f)\right|}{q_d(x_d,f)} \frac{\gamma_d}{\gamma_o}$$



The uncertainty associated with source amplitude is major contribution to error budget.

1) inherent variability in the drive voltage and the source plate response (small)
2) non-constant drag forces on the catamaran (depth/orientation variability)

Can reduce variance by: $$\left|R(\theta_b, f)\right| = \left|\frac{p_r(x,f)}{p_d(x,f)}\right| \frac{q_d(x,f)}{q_d(x_d,f)} \frac{\gamma_d}{\gamma_o}$$

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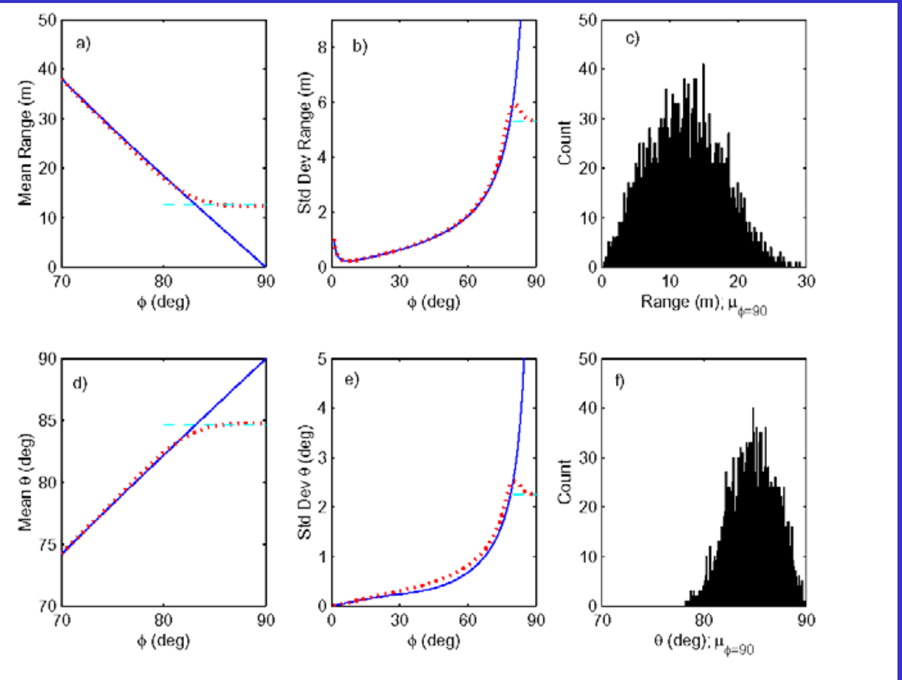
Uncertainty Analysis: Angles

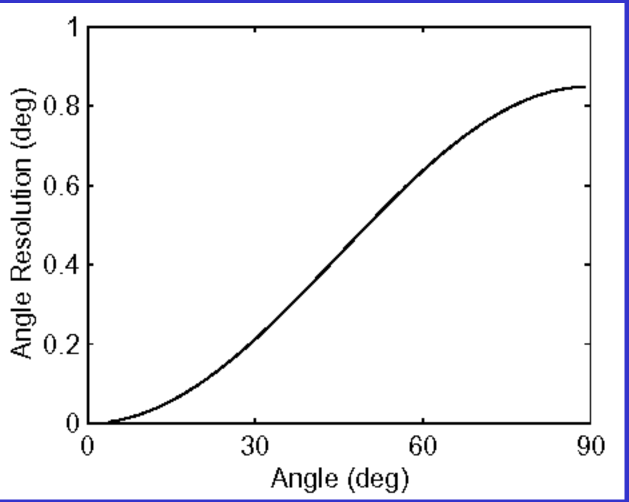
$$x = \left| (c\tau)^2 - (D - S - h)^2 \right|^{1/2}$$

$$\sigma_x = \mu_x^{-1}\left[\mu_c^2 \mu_\tau^2 \left(\sigma_\tau^2 \mu_c^2 + \sigma_c^2 \mu_\tau^2\right) + \left(\mu_D - \mu_S - \mu_h\right)^2 \left(\sigma_D^2 + \sigma_S^2 + \sigma_h^2\right)\right]^{1/2}$$

$$\sigma_\theta = \mu_x^{-1} \cos^2 \mu_\vartheta \left(\sigma_D^2 + \sigma_S^2 + \sigma_r^2 + \sigma_x^2 \tan^2 \mu_\vartheta\right)^{1/2}$$

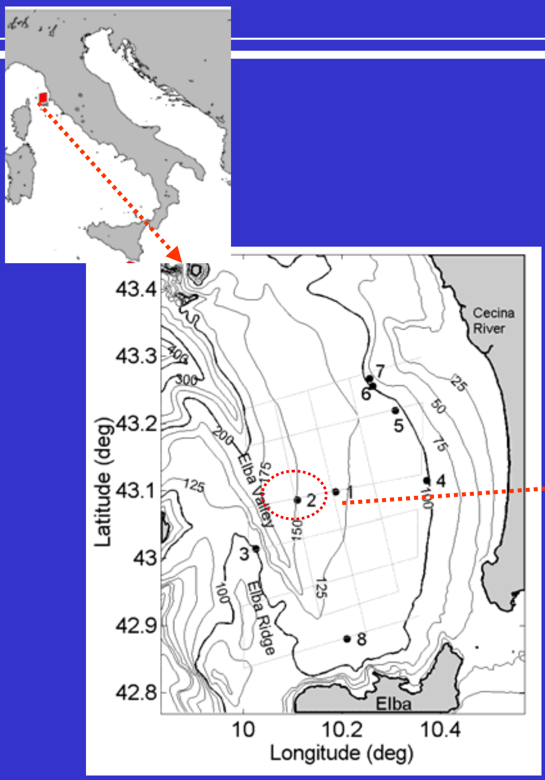


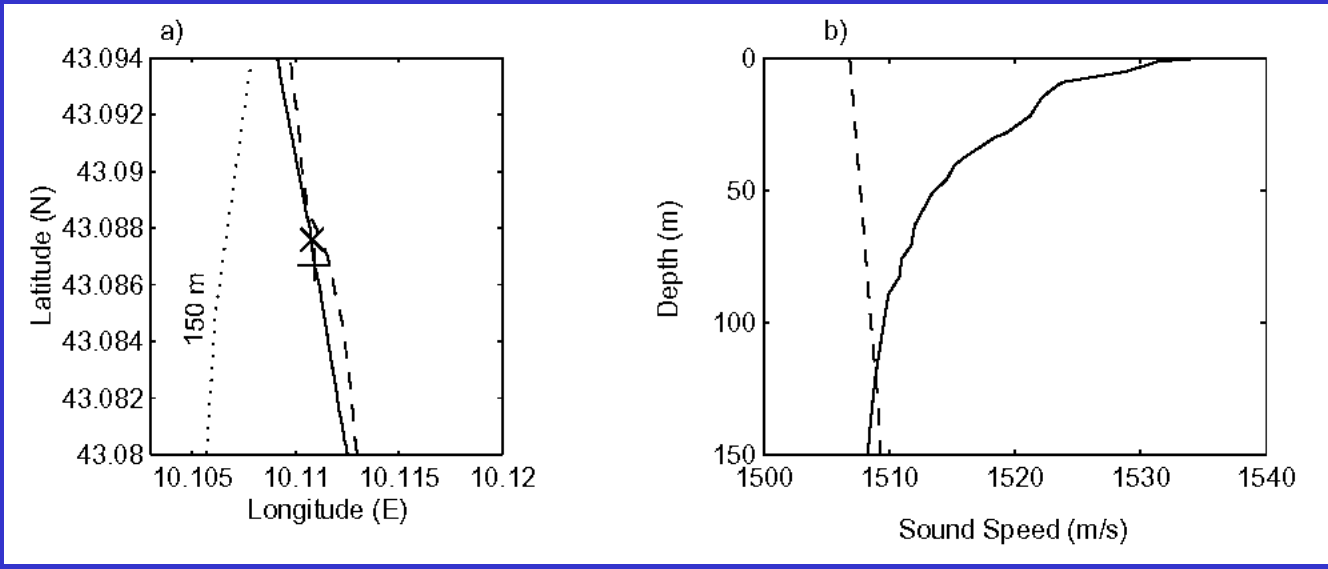
Resolution



NB resolution(θ)- variance(R) tradeoff can minimize overall uncertainty

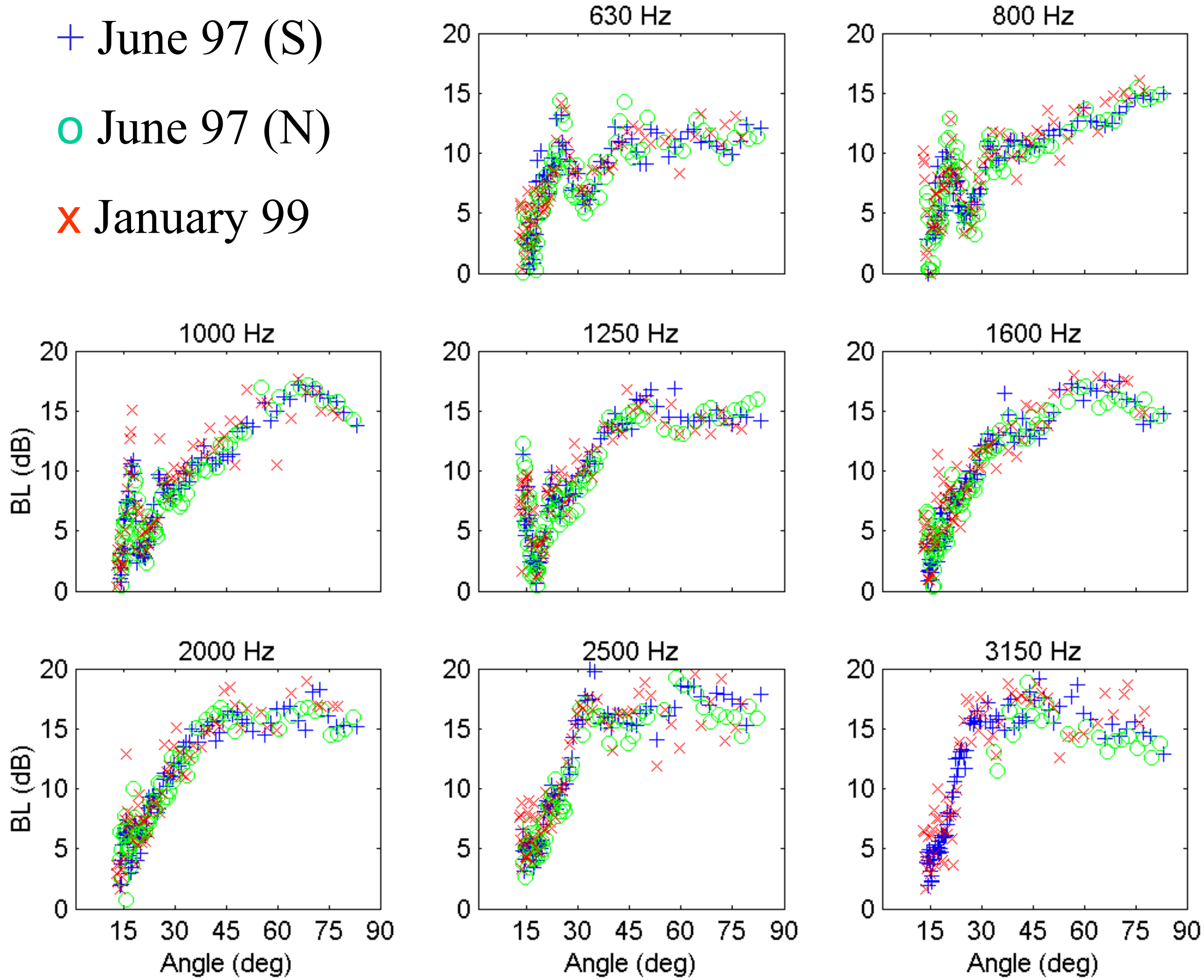
Measurement Repeatability





3 data sets were collected in the Northern Tyrhennian Sea in 1997 (+, solid) summer and 1999 (x, dashed) winter. Array positions differ by ~100m

Uncertainty: Multiple Observations



BL errors

Mean Δ –0.8 to 1 dB

σ=.5-1.4 dB

Angle errors, σ_θ

θ	Model σ	Data σ
25º	0.16º	0.12º
32º	0.20º	0.22º

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Transferring Uncertainty in *R* to geoacoustic uncertainty

Bayes theorem provides a fully non-linear approach to geoacoustic parameter and uncertainty estimation

The solution to the inverse problem is characterized by its posterior probability density: $P(m|d) \propto L(d|m)\, P(m)$

$$L(\mathbf{d}|\mathbf{m}) = \frac{1}{(2\pi)^{N/2}\prod_{i=1}^{N}\sigma_i} \exp\left\{-\frac{1}{2}\sum_{i=1}^{N}[d_i - d_i(\mathbf{m})]^2/\sigma_i^2\right\},$$

$$\langle\mathbf{m}\rangle = \int \mathbf{m}'\, P(\mathbf{m}'|\mathbf{d})\, d\mathbf{m}',$$

$$\mathbf{C} = \int (\mathbf{m}' - \langle\mathbf{m}\rangle)\,(\mathbf{m}' - \langle\mathbf{m}\rangle)^T\, P(\mathbf{m}'|\mathbf{d})\, d\mathbf{m}',$$

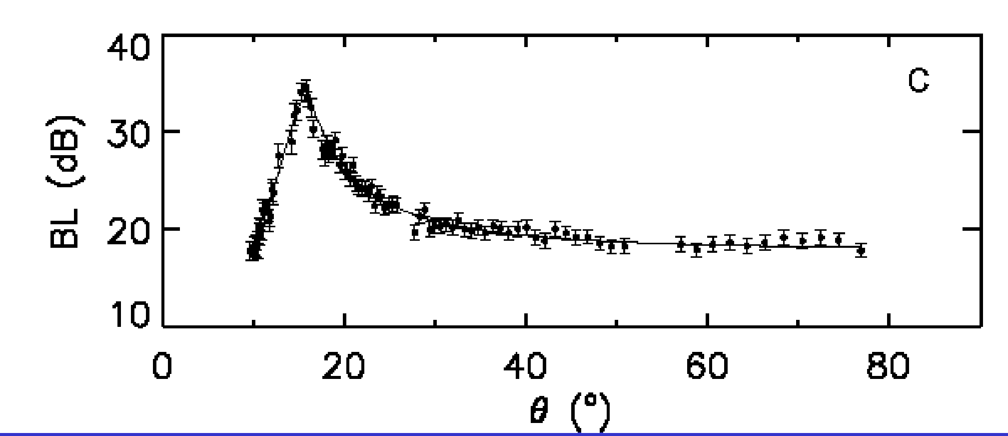
$$P(m_i|\mathbf{d}) = \int \delta(m_i' - m_i)\, P(\mathbf{m}'|\mathbf{d})\, d\mathbf{m}',$$

indicated by:

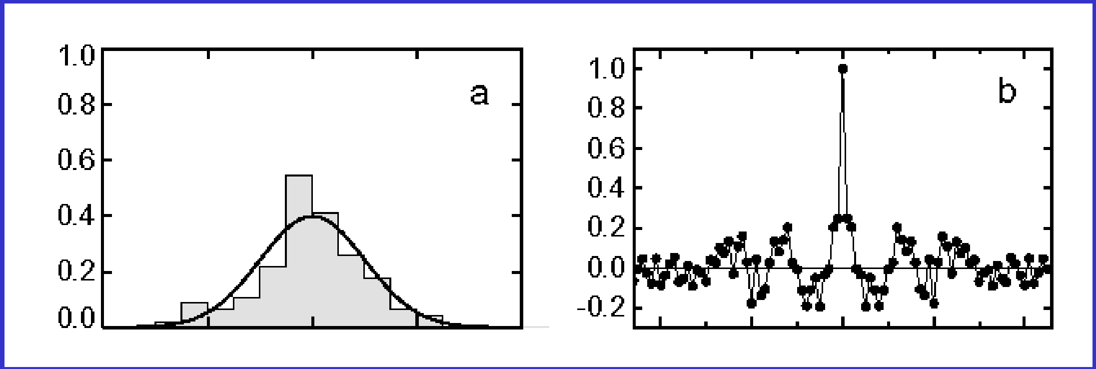
- Statistics of data residuals
- Comparison to synthetic inversion

Optimal Fits for *R*

Measured Data and Fits



Fit Statistics



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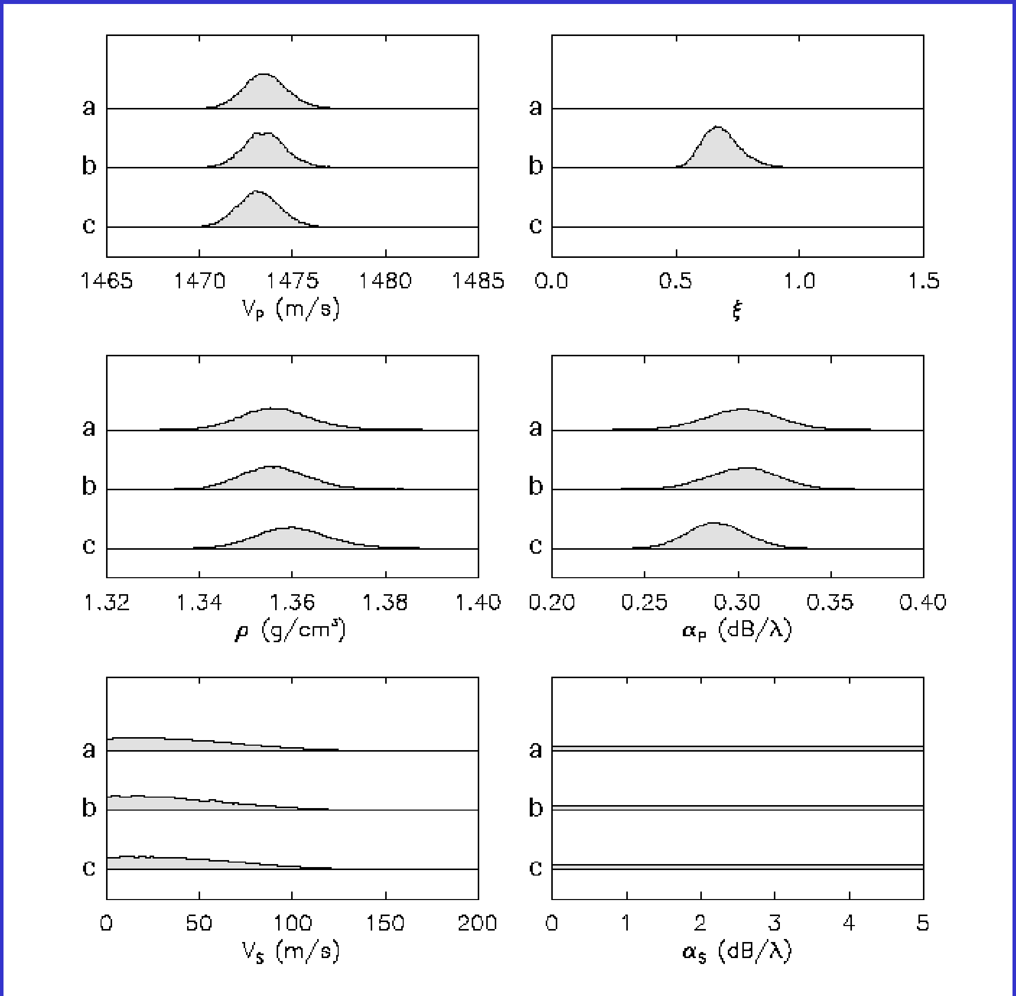
Marginal Probability Dist.



Maximum a posteriori (MAP)

c_p = 1474 ± 2 m/s

α_p = 0.28 ± 0.03 dB/λ

ρ = 1.36 ± 0.02 g/cm^3

c_s = 5 ± 100 m/s

α_s = 1.9 ± 3 dB/λ

95% HPD credibility intervals

c_p = [1472 1477] m/s

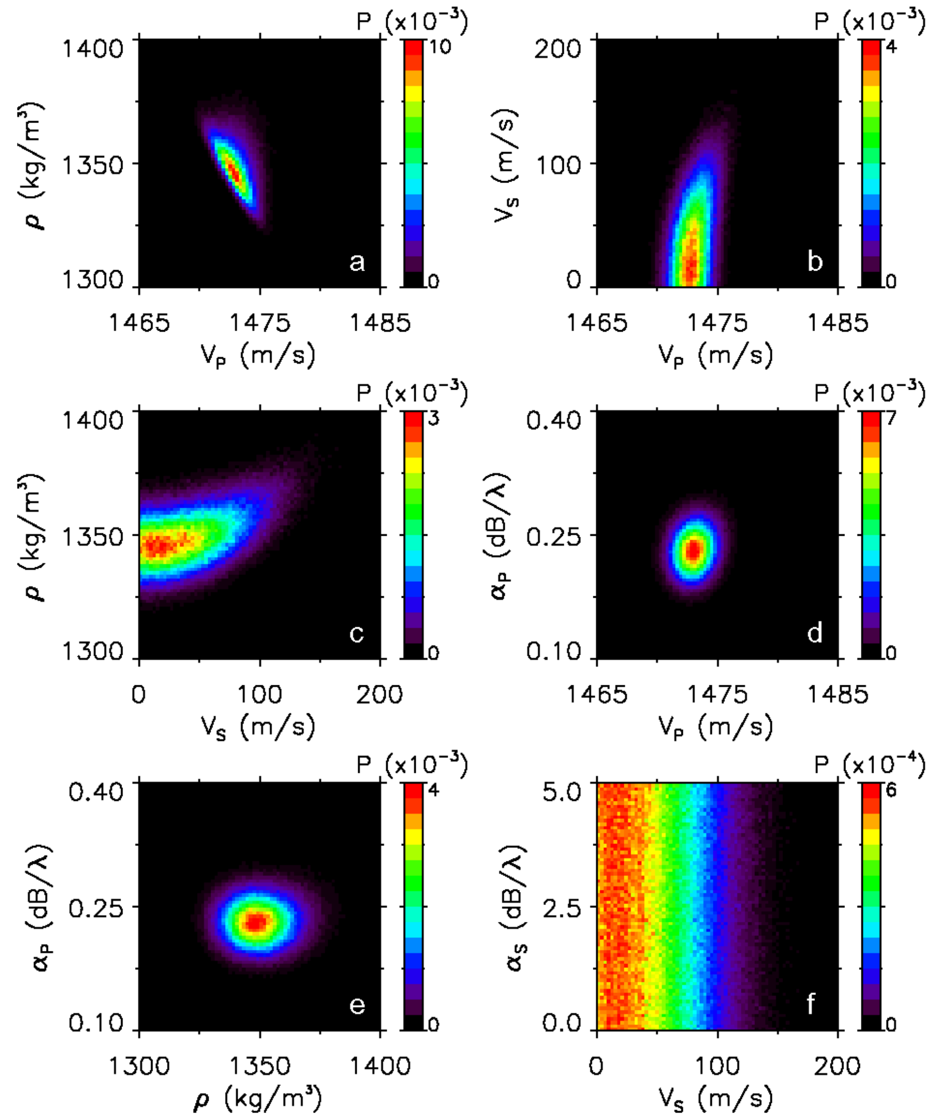
α_p = [0.25 0.31] dB/λ

ρ = [1.34 1.38] g/cm^3

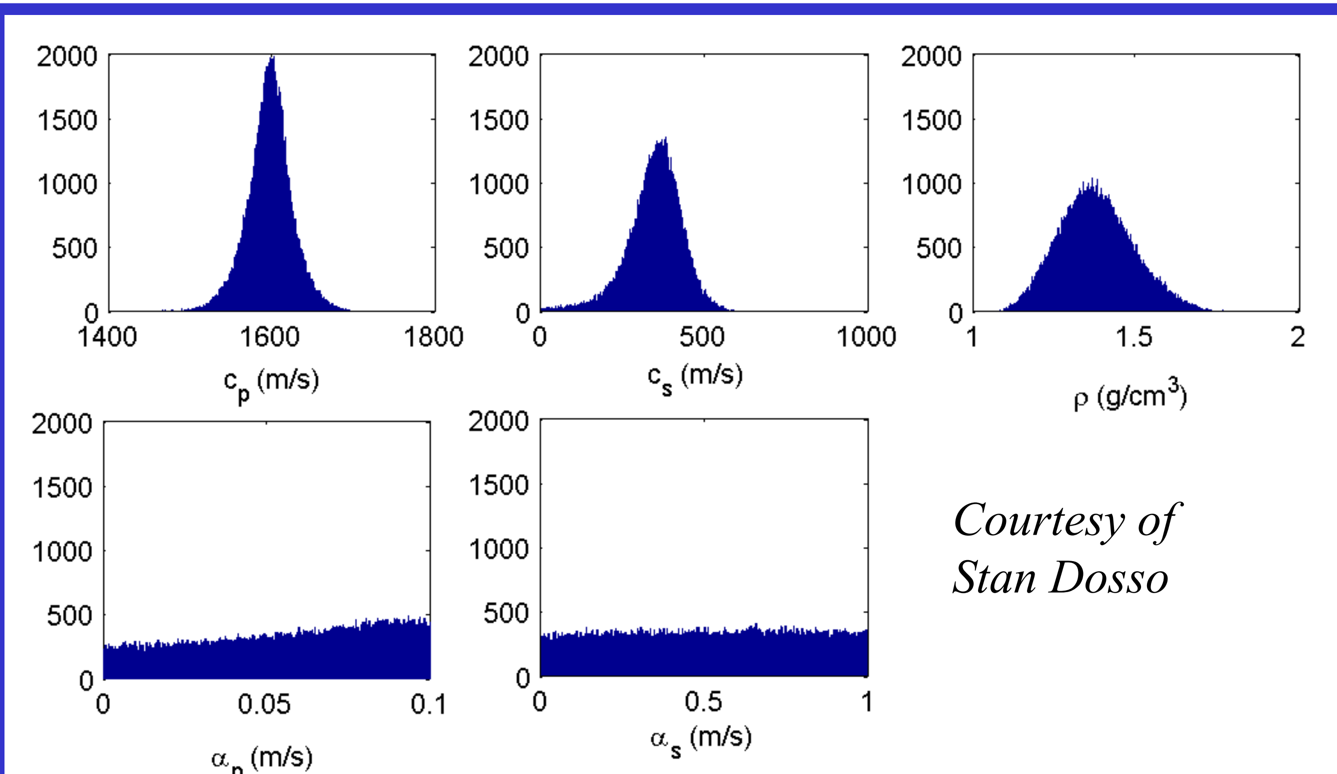
c_s = [0 90] m/s

α_s = [0.2 5] dB/λ

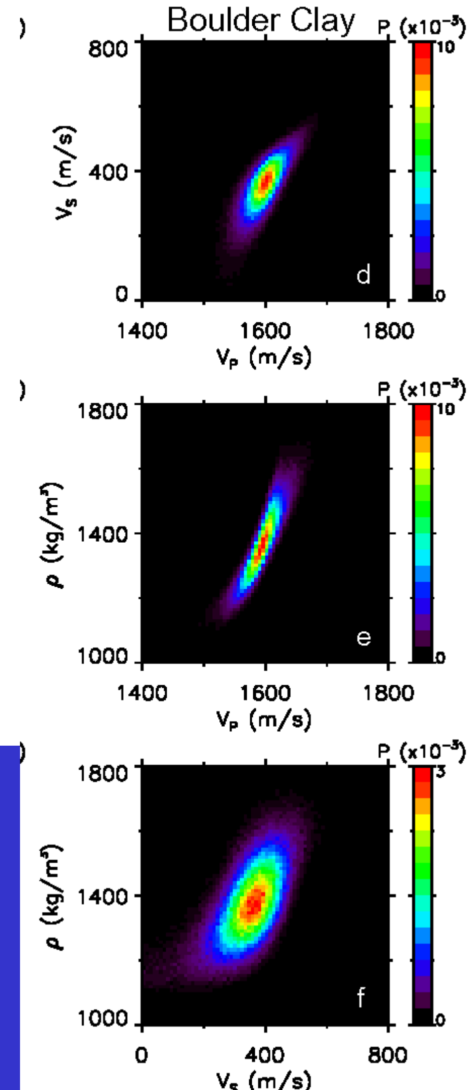
Joint Marginal Prob Distributions



PPD: Boulder Clay



Courtesy of Stan Dosso

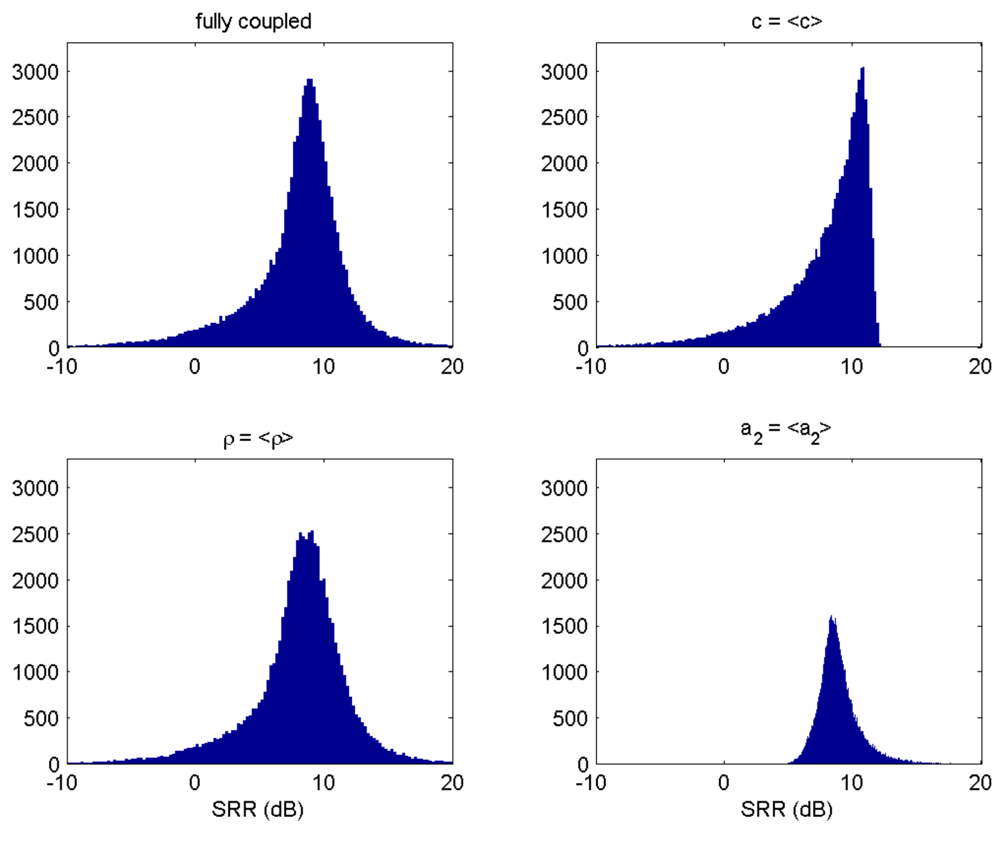


Geoacoustic Uncertainty to Signal to Reverberation Ratio (SRR)

For Pekeris waveguide, r>3 km; Lambert

$$\mathrm{SRR} \sim \frac{S_T \pi \alpha}{H \mu \Phi c t_p}$$

Harrison/Weston



$10 \log(S_T) = 10$ dB (target strength)
$10 \log(\mu) = -27$ dB (scattering param)
H= 100m (water depth)
$\Phi = 2°$ (beam width)
$t_p = 50$ ms (pulse length)

$$\alpha = \frac{\rho_2}{\rho_1} \frac{\beta}{(1-\beta)^{3/2}} \frac{a_2}{10\pi \log(e)}; \quad \beta = \frac{c_1^2}{c_2^2}$$

$\rho_2\, c_2\, a_2$ from PPD

Attenuation (a_2) dominates SRR uncertainty for this PPD

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Summary

1. Developed approach to quantify uncertainty of seabed reflection measurements *(JASA, accepted for publication)*
   - uncertainties of ±0.5-1.5 dB; can be reduced by angle averaging

2. Transferred measurement uncertainty to geoacoustic uncertainty using Bayesian approach (with Dosso, *JASA in review*)
   - gave consistent results for a variety of error estimation approaches (indicating results are robust)
   - yield very high precision estimates of density, comp. velocity and attenuation

3. Demonstrated how geoacoustic uncertainty affects signal-to-reverberation ratio (Harrison, *JASA in review)*
   - uncertainty dominated by comp. attenuation in this case